B. Surface Erosion

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Introduction

Surface erosion occurs when detachable soils on sufficiently steep slopes are exposed to overland flow and/or the impact of rainfall. Sediments introduced to streams from surface erosion processes are generally fine-grained and can influence water quality and aquatic habitat. Watershed analysis is primarily concerned about identifying locations and activities that deliver sediments to these public resources.

Raindrop splash, freeze/thaw, dry ravel, and biogenic processes such as wind throw and animal burrowing are natural causes of soil detachment. Gravity and overland flow of water are natural transport mechanisms of the detached soil particles. Overland flow of water rarely occurs under natural forest conditions because the soil is usually protected by an absorbent, protective layer of organic material resulting from residue of the forest plants. Soil compaction can lead to overland flow and serious erosion consequences. Hillslope angle, soil texture as it affects how well the soil holds itself together, and climate are important influences on the inherent erosion hazard of the site.

Any activity that strips the protective duff layer to the bare mineral surface may allow surface erosion. Surface erosion can also occur on compacted surfaces where the capacity of the soil to quickly absorb free water is diminished. The result is that water is readily channelized into surface flows. Among the activities most likely to cause surface erosion are roads, silvicultural practices involving high intensity broadcast burns or mechanical scarification, poor yarding practices, and natural processes such as wildfire.

Forest management activities that accelerate soil detachment and transport include:

Those that expose bare mineral soil to the weather:
- Road construction and maintenance
- Yarding techniques that disturb the duff layer such as skidder/tractor yarding, no suspension and one end suspension cable yarding
- Site preparation techniques such as burning or scarification

Those that compact soil and/or intercept subsurface flow zones, encouraging overland flow include:
- Skid trails
- Road and landing construction

If water bars and other water control measures are neglected, runoff from roads, cut- and fill-slopes, skid trails, etc. can contribute to hillslope erosion. These features actively produce sediment in most watersheds, with construction practices and drainage design influencing how much sediment is delivered to streams.

How far material can be transported on slopes, and how it behaves once it enters the stream, are largely determined by the nature of the slope and the texture of the sediment.

Factors that influence delivery to the stream system include:

Hillslope Erosion

- Proximity of erosion to the stream system
- Slope angle
- Soil texture, reflecting differences in the distance that various particle sizes will travel
- Areas where overland flow occurs

Road erosion

- Amount and condition of road prism area that drains directly into the stream system
- Traffic levels on the direct entry area of the road surface
- Material used for road surfacing

Some of the natural conditions that limit delivery of eroded soil to the stream include vegetated areas along streams that can filter out soil particles, and topographic conditions that prevent eroded material from entering the stream. Management practices that can limit delivery of eroded soil from hillslopes to the stream system include minimizing duff disturbance, water-barring and/or grass-seeding exposed areas near streams, and avoiding compacting the soil. Minimizing the road surface area that delivers directly into the stream, maintaining it according to the traffic levels, and limiting traffic during wet weather are management techniques that may help control the entry of erosion material into streams.

Critical Questions

The purpose of the surface erosion assessment module is to guide development of information necessary to address key questions critical to understanding erosion processes in a watershed context. Two types of erosion processes are addressed in the module, with the same critical questions for each source:

Hillslope Erosion

- What is the hillslope *erosion potential*?
- Are *contributing activities* present?
- Is sediment *delivered* to streams?
- What areas are *sensitive to forest practices*?

Roads Erosion

- What are the roads' *erosion potentials*?
- Are *contributing activities* present?
- Is sediment *delivered* to streams?
- What roads are *sensitive to forest practices*?
- What is the *potential effect of sediment* on public resources?
- What is the *baseline* sediment level?
- What are the amounts and types of sediment contributions from forest practices?

Answering these key questions relies on a combination of maps, aerial photos, and field observations. A series of exercises designed to answer the critical questions, or identify more information necessary to do so, are provided in the module. The module is designed to generate the level of information necessary to introduce sound information into land use decision-making.

Assumptions

A number of fundamental assumptions underlie the approach developed here. These assumptions dictate a rigorous, yet flexible, framework for the analysis. Our primary assumptions include:

Hillslope Erosion Assessment

- Sheet erosion of hillslopes is influenced primarily by soil type, hillslope gradient, protective cover, precipitation intensity and human activity (USDA, ARS in press).
- Certain soils (easily detachable) and slope conditions (steeper) are conducive to surface erosion (USDA, ARS, in press).
- On potentially erodible soils, the primary factors determining whether surface erosion occurs are exposure and compaction of mineral soil. Surface erosion tends to increase with exposure and/or compaction (Packer 1951).
- Certain forest practices can expose and/or compact surface mineral soil and significantly increase surface erosion. High-intensity burns, such as those used in site preparation, can expose large areas of mineral soil (Tiedemann et al. 1979). Both ground-based and cable yarding harvest activities have the potential to expose and compact surface mineral soil. The extent of soil disruption tends to be higher on ground-based harvest sites due to the skid trails (Megahan 198). Harvest activities that do not expose or disrupt the surface mineral soil are unlikely to increase surface erosion (Bennett 1982).
- Rainfall intensity and amount influence whether soils erode; however, since all places in the state of Washington have some probability of intense rainstorms, they also have some probability of surface erosion.
- If gullying occurs and the gullies connect to the channel network, then all sediment carried through them will be delivered to the stream system.
- Surface erosion may be delivered anywhere in the stream system by dry ravel or overland flow, but is fairly easily disrupted by buffers of slash, duff and other protective soil cover. Therefore, sediment is generally not delivered to the stream system if adequate buffers exist on the hillslopes (Comerford et al. 1992).

- Visible evidence of surface erosion is present where surface erosion has occurred in recent years.

- Dry ravel is primarily a function of slope gradient, hillslope storage potential, and soil erodibility (Mercereau and Dyrness, 1972).

- Most surface erosion occurs within five years of a contributing activity (Mercereau and Dyrness, 1972).

- The Forest Practices Rules of the State of Washington (WAC 222) are followed, unless evidence suggests otherwise, and the rules are effective at preventing excessive surface erosion, unless the soils are especially erosive.

Roads Erosion

- Surface erosion occurs from nearly all roads. However, excluding special problem sites, sediment delivery to channels only occurs:
  1. When ditches or culverts drain near the channel (within 200 ft). Within this zone, the sediment delivery ratio is 100% (Burroughs and King 1989).
  2. Within a 200-foot buffer distance from the stream at other locations, delivery is based on the probability of downslope sediment transport. Outside the buffer zone, sediment supply to streams is assumed to be inconsequential because of the low probability of delivery (Ketcheson and Megahan unpublished report; Burroughs and King 1989). The buffer zone can be adjusted based on field evidence. The justification for such an adjustment should be explicitly included in the summary report.

- During wet weather, heavily trafficked roads produce substantially more sediment than do abandoned or low-use roads (Reid and Dunne 1984; Sullivan and Duncan unpublished report).

- Roads meet current Forest Practices Rules specifications, unless observed otherwise.

- Most road construction sediment is produced within the first two years of life of the road, but may continue at a reduced rate for long periods (Megahan 1974; Burroughs and King 1989).

- Ridge-top roads not draining to defined channels are considered to be non-contributing and not included in the assessment unless field evidence suggests otherwise.

Background Sediment Calculation

- A rough calculation of the baseline sediment supply to the stream can be made from estimates of stream channel length, soil depth, and creep rate.
- Comparing sediment yield from forest practices to the baseline can provide a means of rating the sediment hazard to streams posed by forest practices.
- There may be confounding conditions where the baseline comparison is not appropriate, such as basins where mass wasting is particularly active.

Overview of Assessment and Products

Before reading this section, the analysts should review the first three paragraphs under "Overview of Approach" in the Mass Wasting module.

The objective of the surface erosion assessment is to generate key information that addresses the critical questions for the watershed. During the course of the assessment, the analyst will establish:

- The relative *potential* for surface erosion from hillslopes,
- *Contributing land use practices* influencing surface erosion from hillslopes and *delivery* to streams,
- The relative *potential* for surface erosion from road surfaces based on road construction and drainage design,
- Effects of *contributing activities* of traffic on road sediment production, and *delivery* to streams,
- *Background* sediment yield from the watershed (excluding mass wasting processes), and
- The magnitude of *effect* on sediment supply from mapped sources.

Each of these objectives is an integral component of the surface erosion assessment. To determine background sediment yield, the watershed is divided into sub-basins (on MAP B-1) usually of the Type 3 streams, and a background sediment yield is calculated as a function of soil depth, creep rate, and stream length.

Using an erosion potential mapping process, based on terrain (steep slopes erode more) and erodibility of the soil (soil K factor), the analyst develops a Preliminary Soil Erosion Potential Map (Map B-2). This can be done from soils, geology, or the DNR Soil Erosion Potential maps. These maps represent an initial hypothesis of potential surface erosion, producing ratings of high, moderate, and low.

To validate the initial hypothesis, the analyst uses aerial photography and field observations to determine whether erosion is actually occurring. To do so, they evaluate sites with recent management activities. Landowners supply information during Start-up on their forest activities in the past 5 years. These are compiled on the Past 5 Years Activities Map (Map B-3). The analyst uses aerial photos and field visits to determine what level of impact these forest practices have had on causing erosion in representative sites or each of the rated areas. Observations relevant to erosion from recent forest practices are recorded on the Hillslope Field/Photo Assessment Form (Form B-1).

When surface erosion is observed, the analyst estimates the likelihood of delivery to the stream system. Sediments not delivered to streams, wetlands, or lakes are not considered to have an effect on public resources. When delivery is established, a surface erosion unit is identified.

To determine these units, the analyst revises the soil erodibility map to more accurately reflect where surface erosion occurs and is delivered to a stream system as a result of forest practices. (Final Soil Erosion Potential Map, Map B-4). The High, Moderate, and Low ratings on this map are the hazard ratings used in the Rule Matrix to determine whether special prescriptions need to be written for these areas. The amount of surface erosion contributed to streams is not required unless dramatic or important surface erosion sites are contributing to a stream system. This reflects the assumption that surface erosion resulting from today's forest practices tend to occur sporadically.

Roads are also assessed for erosion potential. Landowners, during the start-up phase, supply the preliminary information on road use and surfacing materials, which is compiled on Map B-5, Landowners Roads Information Map. Roads are divided into segments based on parent material, surfacing material, and road use. Similar road segments are grouped and these groups are analyzed for sediment delivery to streams. Sediment production is predicted (using Form B-3) based on field observations (recorded on Form B-2) of road condition, drainage system design, and assumed truck traffic use rates. The analyst will not be able to inventory the entire road system in most cases, but will sub-sample various road categories. These results are extrapolated to the remainder of the basin. A Road Sediment Delivery Map, Map B-6, is produced that shows the rates of sediment delivery predicted for roads of each type in each sub-basin.

Since road sediments are a persistent and widespread source of fine sediments, the predicted amounts of sediment from roads for each sub-basin are compared to the background rate for the sub-basin. These estimates help determine a hazard rating for road sediment. These ratings are used in the Rule Matrix to determine if special prescriptions are needed to protect public resources

Qualifications

The Surface Erosion Module provides a structured approach to assessing surface erosion hazards on a watershed basis. The module is not a cookbook, and some expertise in recognizing and evaluating surface erosion is required to effectively complete the surface erosion assessment. In addition to completing the Watershed Analysis Training provided by DNR, the surface erosion analyst must possess the following skills, education, and experience at a minimum.

Skills: Level 1
Knowledge of soil science, hillslope processes (including erosion, transport and deposition), and their relationship to forest management activities.

Skill in use of soil maps, air photo interpretation, and recognition of surface erosion features in a variety of geomorphic settings.

Working knowledge of Universal Soil Loss Equation.

Familiarity with forest management activities potentially affecting surface erosion in a region.

Additional Skills: Level 2
Familiarity with methods of sediment budgeting.

Education and Training: Level 1
Bachelor's degree in soil science or geomorphology, *or* in a related field such as forestry, forest engineering, geotechnical engineering, geology, geophysics, etc.

With a significant amount of course work or other training in geomorphology and/or surface erosion processes.

Additional Education and Training: Level 2
Master's degree in soil science or geomorphology, *or* in a related field.

With a significant amount of course or thesis work or other training in geomorphology and/or erosion processes.

Experience: Level 1
At least 2 years of field experience in assessment, scientific management, or research on erosion in forest lands or mountainous areas.

Additional Experience: Level 2
At least 2 years of field experience in assessment, scientific management, or research on erosion in forest lands or mountainous areas, including substantial experience with field interpretation.

Two additional years of relevant experience may be substituted for the Master's degree. No years of field experience are required with a PhD in a closely relevant field.

Background Information

All of the information necessary to complete the module, with the exception of field information, must be gathered prior to starting an assessment to ensure that the analyst will be able to complete the analysis in a timely manner.

Base Maps

The final products of the Hillslopes and Roads portions of the module will be plotted at 1:24,000 scale, compatible with DNR's Geographic Information System (GIS), on mylar. These maps may be plotted by hand or by GIS, but they must be on the official base map. Two copies of the base map on mylar showing the watershed analysis unit (WAU) boundary, section lines, hydrology and roads will be needed to plot the final products, if plotted by hand. These base maps can be obtained from the DNR regional office. If a GIS system is to be used to produce final products, it must be compatible with DNR's GIS system, using the same projections, etc. Consult the GIS person at the DNR regional office for more information on fitting GIS information to DNR's system.

It may be useful to have two additional copies of the base map plotted on mylar for use in producing intermediate products - one to be used to compile all landowners information on activities of the past 5 years, and another to be used to compile all landowners roads information.

Where possible, the entire analysis team should decide on the sub-basins to be used early during the process. The boundaries for these should be digitized at the DNR regional office, or on a landowner's compatible GIS, so that they can be included on plots of the base map. The sub-basins boundaries must otherwise be plotted by hand onto all maps.

Other Maps

For the Hillslope portion of the module, the analyst will use topographic maps, geology maps and descriptions, soil maps and descriptions, maps of activities of the past 5 years as provided by the landowners, and the DNR GIS layer "Soil Erosion Potential". Soil maps can usually be acquired from the local USDA Soil Conservation Service (SCS) Office for the counties involved. The USDA-Forest Service usually has Soil Resource Inventory (SRI) maps and descriptions available at the local Ranger District Offices. DNR has soil maps of DNR-managed lands, and often include adjacent land as well. Some private forest land owners have their own soils maps which may be useful.

Where possible, digitize the compiled landowners' past 5 years activities map. This will ease producing information on amounts of various activities on various erosion potentials. In addition, for the Roads portion of the module, landowners' maps of road use and surfacing will be needed.

Aerial Photographs

Access to a recent set of 1:12,000 scale aerial photographs will be necessary. The Mass Wasting analyst will be using a series of older photos, which may be consulted.

Other Information

Reports on various aspects of surface erosion may have been produced in the past for various landowners in the basin. For example, the Forest Service may have done some analyses or reports on portions of their ownership that coincide with the WAU. Inquiring of each ownership for any relevant reports may provide some useful background and supporting material for the analyst. Likewise, important water bodies may have been studied in the past, and information relevant to surface erosion may be available on them. Local Counties and citizens groups may have carried out studies which resulted in reports, maps, etc.

All of the information, maps, photos should be *in hand* before the analysis begins. There is often a month or more involved between requesting information from various sources and receiving it. With the limited time frame of Watershed Analysis, the analyst will need to ensure background information is already assembled at Startup when the assessment is initiated.

Analysis Procedure

There is a certain level of information necessary to analyze surface erosion processes in a watershed context. The following procedure defines a standard methodology appropriate for watershed analysis and must be completed regardless of the qualifications of the analysis team.

Level 1 and Level 2 watershed analysis levels specify the qualified individuals and time frame available for the assessment. Limitations of time and resources for performing the assessment, and the analyst's qualifications, will also determine the degree of resolution and confidence in assessment interpretations.

It is expected that Level 1 assessments produce the standard products, but greater uncertainty of results and indeterminate interpretations are expected. It is important that uncertainties be noted so that decisions based on this information can account for them. Where resolving uncertainties is considered important for improving interpretations and decision-making, a Level 2 assessment may be appropriate. Level 2 teams are expected to produce the standard assessment products augmented by additional information on specific situations. Level 2 analysis can be invoked when analysts are not satisfied with their ability to answer one or more critical questions based on the standard analyses. Level 2 assessment requirements are flexible, allowing the analyst to invest his or her effort in gathering data and observations as warranted by the nature of the question to be answered and the watershed situation to be resolved. This may include more defined analyses of particular processes or sub-areas within the watershed.

The surface erosion assessment is divided into two parts:

The Hillslopes section accounts for surface erosion occurrences, or potential for surface erosion, on hillslopes.

The Roads section assesses the amount of erosion that can be expected from the roads in the basin. Roads can be chronic sources of surface erosion that can contribute sediment for the life of the road.

Surface Erosion Links

Following is a summary of points for which the surface erosion analyst will need to touch base with others during an analysis. Initial contact during Start-Up (SU) is important for many of these items. Some of these items suggest preliminary synthesis discussions (SYN).

Landowner/DNR - sources of information

- road surfacing/traffic (SU)
- road problems (SU)
- areas harvested in past 5 years (SU)
- harvest methods, site prep methods (SU)
- wildfire history (SU)
- availability of a guide/helper

Mass Wasting Analyst

- agree on who is covering road failures (SU)
- agree on who is covering orphan roads (SU)
- agree on who is estimating landslide scar erosion (SU)
- discuss relative importance of various sediment sources (SYN)

Hydrologic Change Analyst

- agree on sub-basins (SU)
- source of rainfall information for roads analysis

Riparian Analyst

- may see evidence of sediment reaching streams across riparian areas
- in conjunction with the channel analyst, discuss role of woody debris in Type 4 & 5 streams (SYN)

Stream Channel

- agree on who is covering stream bank erosion (SU)
- along with Mass Wasting analyst, discuss relative importance of various sediment sources (SYN)
- along with Riparian Analyst, discuss role of woody debris in Type 4 & 5 streams (SYN)

Fish Habitat

- discuss sediment sources in relation to presence of fine sediment in fish habitat (SYN)

Water Supply/Public Works

- discuss sediment sources in relation to presence of fine sediment in water supplies (SYN)

Watershed Partitioning

Sub-division of the WAU into sub-basins will allow tracking the effects of sediment on public resources on a more localized basis assuming that the relative influence may not be uniform throughout a watershed the size of a WAU. Although the analyst will not use the sub-basin divisions until later in the assessment, early identification of these in conjunction with the hydrology assessment team will facilitate compiling data and results in a manner conducive to later steps.

The WAU may be sub-divided into Type 3 stream basins. The surface erosion analyst should consult with the hydrology analyst on the identified units, since the hydrologist also uses Type 3 basins as one criteria for hydrologic analysis units. The sub-basin units are placed on the base map of the watershed. The sub-basin boundaries will be transferred to the hillslope erosion maps and the roads erosion maps. Later steps in the assessment will estimate sediment yield from surface erosion sources throughout the WAU. The sediment rates will be estimated at the mouth of each sub-basin based on soils, road characteristics and hillslope conditions in the sub-basin based on results from the assessment.

Surface Erosion From Hillslopes Assessment

The potential for surface erosion from hillslopes is primarily a function of the characteristics of the soil, the steepness of the terrain, and the vegetation cover. The Washington Forest Practices Rules contain standard rules intended to protect public resources from the effects of excessive erosion from timber harvest (WAC 222-30). Experience with operations performed under these rules is that forest activities *generally* do not result in widespread increased surface erosion. However, it is also possible to improperly conduct activities so that significant amounts of sediment from surface erosion are delivered to streams. It is important to note that erosion problems from improperly conducted activities can occur anywhere on the landscape. However, erosion damage is most likely in the more erosive areas.

The focus of the hillslope portion of the module is to locate the potentially erosive slopes in order to map areas sensitive to forest practices conducted according to the standard rules as applied in that area. Because of the importance of the interaction between inherent site erodibility and the manner in which a forest practice is applied, determining the sensitivity of an area to hillslope surface erosion requires consideration of both. Erosion potential is estimated by mapping soil properties and slope. Sensitivity is determined when potential is confirmed because actual erosion problems are found in the field. The analyst will have to sort out from field observations whether surface erosion appears to result from standard rules on sensitive soils or slopes, or lack of compliance with standard rules.

For these sensitive areas, the Rule Matrix will show whether prescriptions will be needed from the field managers team to provide protection of public resources. Standard rules will remain in place in all areas where prescriptions are not required.

In the Hillslopes portion of the module, the analyst examines the *potential for erosion,* the effects of *forest activities* on the different erosion potentials, and the *delivery* of erosion products to the stream system. The analyst then provides information on *areas sensitive to forest practices.*

Surface Erosion Potential

Different parts of the basin landscape have different inherent rates of surface erosion. Some soils are composed of easily detached material that is mobilized with minimal disturbance. Other soils require considerable disturbance or compaction to cause soil particles to be detached and displaced. In addition to the inherent soil properties, the slope on which the soil lies affects how easily it is eroded. A soil on a steep slope is more likely to erode than the same soil on a gentle slope because of the effects of gravity. The first step in evaluating the potential for erosion on hillslopes is to develop a map of the soils with greater and lesser likelihoods of erosion. A soil erosion potential map will be developed that includes effects of slopes and soil erodibility. There are a variety of ways to obtain or develop an appropriate soil erosion potential map.

DNR Soil Erosion Potential Map

The simplest way is to obtain the DNR Surface Erosion Potential Map from DNR's GIS. On these maps, soil types are already rated for erosion potential using principles similar to those on which this module is premised. However, this map should be viewed as a preliminary estimate, since the soil surveys on which they were based were conducted based on silvicultural rather than engineering specifications. These maps need to be field verified, and difference in actual erosion from the rated erosion potential will not be unusual. The DNR maps are available for most forested lands in Washington through the local DNR Region office.

Other Erosion Mapping Methods

An alternative soil map may be produced by using the K factor assigned to each soil unit from SCS soil surveys, or assigning a K factor using the soil erodibility nomograph from the Revised Universal Soil Loss Equation

(RUSLE) combined with slope. The analyst would need to provide justification for any assigned K values since K values are based on percent silt and sand fractions, soil structure, and permeability. The K factor indicates the influences of soil properties on the effects of rainfall, runoff, and infiltration. Erodibility ratings and slope categories have been grouped into three classes as potential erosion ratings (Table B-1). SCS maps are often available on forest lands in Washington. The K factor for a soil can be usually be found in the tables in the SCS county soil survey, in a table in the back of the survey document, titled "Physical and Chemical Properties of Soils".

Table B-1: Erodibility Ratings Based on K and Slope

Slope Class (Percent)	K < 0.25 Not easily detached	0.25 < K > 0.40 Moderately detachable	K > 0.40 Easily detached
< 30	Low	Low	Moderate
30 – 65	Low	High	High
> 65	Moderate	High	High

The USDA-Forest Service has soil maps and descriptions, called the Soil Resource Inventory (SRI), which contain adequate information to produce a soil erosion potential map for Forest Service lands in the WAU. This information is usually available at the local Forest Service Ranger District office.

If there is an area in the basin for which there are not soil maps, a good soil erosion potential map can be constructed from geologic and topographic maps of the area. A geologic map can be used to identify the general nature for the soils developing on dominant parent material relative to erosivity and the nature of the sediment produced. A rating of erosion potential can be made by using the combination of geology and topography maps, according to Table B-1 above, qualitatively estimating the K factor range from parent material.

Geology, topography, and soils maps will also be useful to interpret and define the DNR Soil Erosion Potential Map units. This initial map is a work tool, not a final product. This “Preliminary Soil Erosion Map”, Map B-2, will be reviewed in light of field evaluations of sites where forest management activities have been carried out in the past 5 years. Field evidence will be used by the analyst to draw a final map of surface erosion sensitive areas.

Contributing Activities

Field evidence of erosion is the primary means of determining the hazards within the watershed for hillslope erosion. Unlike mass-wasting features, surface erosion is difficult to detect with remote sensing techniques and may require field inventories to discover or confirm its occurrence. The primary evidence of surface erosion on hillslopes is gullying, some of which may be visible in aerial photographs.

Observations from local sites are extrapolated to other locations in the watershed through the erosion potential map. The analyst must visit the field, and, based on observations in the field and on photos, modify the preliminary soil erosion potential map to reflect the likelihood of high, moderate, or low occurrence of erosion and sediment delivery to streams from standard forest practices. Field visits focus on sites with activities conducted in the past 5 years, both to identify erosion before it is masked by revegetation, and to reflect current practices.

As part of the Start-up information, the analyst has a map or other information on the land management activities of the past 5 years that would affect surface erosion. These activities include area and type of timber harvest with type of yarding system; area and type of site preparation activities and intensity; location of grazing allotments and rules or improvements required of lessee; areas where off-road vehicle use commonly occurs. The analyst plots all activities on a mylar base map (or more than one map if activity patterns make one map confusing). These activities will be rated for expected erosion impact (see Table B-2). All will be examined on aerial photos, and a field sampling scheme will be developed to visit a variety of activities of different intensities on a variety of terrain.

With the Preliminary Surface Erosion Potential Map (Map B-2), the compiled landowners' Past 5 Years Activities Map (Map B-3), and a recent set of 1:12,000 aerial photos in hand, the analyst can develop a field sampling scheme. All sites from the past 5 years are rated for expected erosion and examined on aerial photos. A subset of these sites are field checked to compare intensity of erosion expected with that existing on the site. The analyst must consider whether the activity was carried out in general compliance with the Forest Practices Rules and whether sediment was delivered to streams. Information generated from the photo and field examinations is recorded on the Hillslope Field/Photo Assessment Form (Form B-1).

Table B-2: Rating Guidance for Contributing Activities

Activity	Low	Moderate	High
Burns	Discontinuous Low intensity Light duff burn	Spotty intense	High intensity 3" deep or more Continuous over a large area
Tractor Logging	Waterbars intact	Spotty evidence of occasional gullying	Skid trails on steep (>10%) slopes Heavy, widespread compaction Waterbars non-functional
Highlead (cable) yarding	Fully suspended logs	SOME deeply gouged haul-back corridors	NUMEROUS, deep gouges from half-suspended logs
Scarification for site preparation	Shovel scarification on gentle slopes	Cat scarification on gentle slopes	Cat scarification on steep (>10%) slopes
Grazing	Animals fenced away from riparian,springs, minimal evidence	Some impact from animals delivered to streams	Springs, riparian areas unprotected, extensive evidence of trampling
Off-road vehicles	Little access to streams, streambanks by vehicles	Some vehicle access to streams	Evidence of running up and down streams, streambanks

Figure B-1 provides a schematic for the hillslope assessment.

Figure B-1: Hillslope Assessment Overview

Preliminary Surface Erosion Potential Map

+

Past 5 Years Activities Map
Start Form B-1 on each activity

+

Aerial Photo Examination → Other sites of interest
Add information to form B-1 ← Record on a Form B-1

Field sampling scheme → Other sites of interest
Add information to Form B-1 Record on a Form B-1

Final Surface Erosion Potential Map B-4
with descriptions of map units rated for
hazard of delivery of surface erosion
material to streams

During the photo and field assessment, other sites may come to light that were not part of activities of the past 5 years, but appear to be eroding and delivering sediment to streams. These sites will also be recorded on a B-1 form and receive the same examination. All sites may be useful in determining trends in amount of surface erosion, in determining recovery rates, or in demonstrating the sensitivity of the soils involved to surface erosion. The analyst must always consider if the forest activities causing the erosion at these sites were carried out according to standard rules for forest practices.

Field Site Selection

Due to time limitations, field site selection must allow efficient visits to as many types of activities and terrain as possible. Field visits for both the hillslopes and roads portions of the module can be carried out together, so consideration of roads to be visited can influence field sampling.

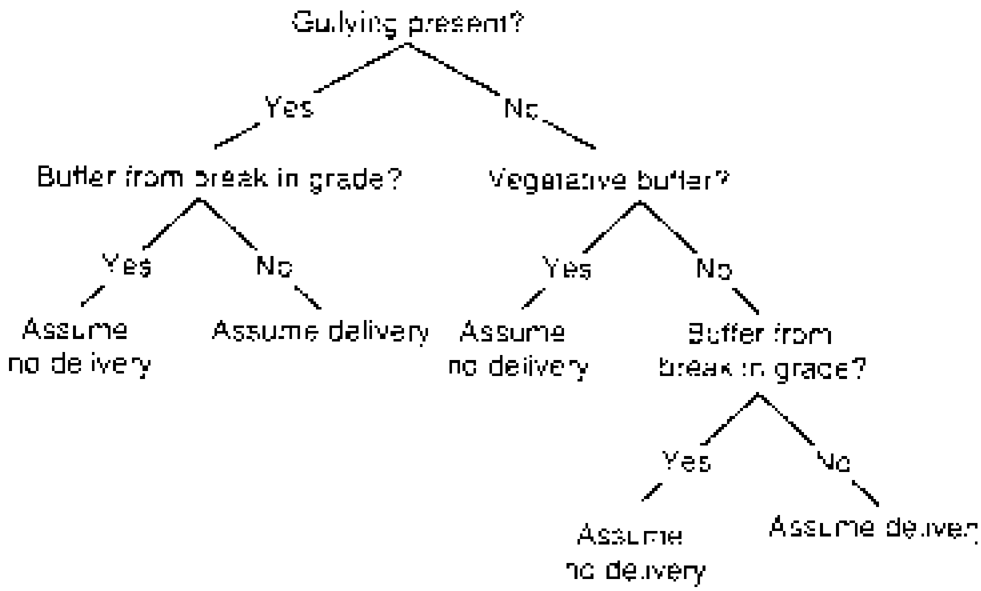
Field visits should include all or most levels of potential erosion and types of activities. Visits should also cover the range of soil erosion potentials. Additional site selection criteria may include varying geology and terrain. The rationale for site selection should be described in the final report.

Delivery

The analyst needs to note not only that erosion is occurring or has the potential to occur, but that erosion products are likely to be delivered to a stream. The final hazard map units are rated for *delivered* hazard. Eroded soil that deposits on-site or where it cannot reach a stream is not of importance to this assessment. Factors that influence delivery include proximity of erosion to the stream system, and the existence of buffering factors such as well vegetated slopes between the erosion and the stream, or a break in topography such as a flat stretch between the eroded site and the stream of sufficient length to prevent erosion materials from reaching the stream. Figure B-2, provides some guidance on the circumstances influencing delivery of sediment to streams. If evidence contrary to the assumed delivery exists, rate delivery according to observed evidence.

The delivered hazard map units may be drawn as a broad area, but in their description be more closely defined. For example, an area may be delineated on the map with an accompanying map unit description that defines the actual hazard areas to be “those areas within 100 feet of a stream channel” within that map unit. Or, a map unit may be drawn, and the accompanying map unit description defining the hazard area as the “steep (>50%) convex slopes” within the mapped unit.

Figure B-2: Surface Erosion Delivery to Streams



Field Form. For each site, the analyst will record observations on a form labeled "*Form B-1*, Hillslope Field/Photo Assessment Form". The exact format of the form is left to the analyst, but must include the following information, at a *minimum:*

— WAU
— Sub-basin
— Site location
— Preliminary Soil Erosion Potential rating
— Type of activity, year
— Activity rating from Table B - 2
— Whether field or photo observation
— Observations, including descriptions of:
  — amount of area affected by erosion
  — erosion type and degree
  — particle sizes of eroding material
  — compaction, if present
  — evidence of overland flow
  — slopes where erosion is occurring
  — apparent causes
  — delivery to stream system

To allow flexibility, the specific layout of the form is left to the analyst. The field forms will be included in the final report as an appendix.

Hillslope Areas Sensitive To Forest Practices

The evidence gathered in the field is used to modify the initial soil erosion potential maps to produce the surface erosion units. The analyst uses all available information from maps, photos, and field visits to determine if areas identified on the Preliminary Surface Erosion Potential Map as high, moderate, or low erosion potential are correct representations of the delivered hazard from surface erosion. This determination is made based on professional judgment of the evidence generated during the assessment. The spatial extent, frequency of occurrence or severity of erosion would tend to suggest a rating of “High”. Localized, occasional or mild levels of erosion would tend to suggest a rating of “Moderate”. Erosion problems resulting from poorly conducted practices should be noted, but not necessarily considered representative of erosion potential under management conducted according to standard rules. The delivered hazard ratings from the final map are used in the Rule Matrix to determine the need for special prescriptions to protect public resources.

Some guiding questions to assist the analyst are provided below:

Are past activities or practices contributing to active erosion? How much area? What is the nature of the sediment?

Did some practice consistently result in erosion on all or certain soil/ slope categories?

Did some practices occasionally result in erosion on all or certain soil/ slope categories?

Did the field reconnaissance yield any insight as to precise problems?

For example, if a unit was logged in the past 5 years with standard practices and a few problem areas, the analyst would rate the activity as likely having a moderate impact. If the analyst then viewed the site on photos or in the field and found excessive erosion, then either the activity was not carried out according to the standard rules, or the soil is especially erodible, and something beyond the standard rules may be needed to protect public resources, depending on the resources’ vulnerabilities. The analyst will have to distinguish between activities carried out according to the standard Forest Practices Rules, and activities which were not, so familiarity with the standard rules on timber harvesting (WAC 222-030) is essential.

The analyst revises the initial soil erosion potential map to reflect observed conditions, producing the Final Surface Erosion Potential Map B-4. Each map unit on the final map will have an accompanying description that describes the location and reasons for delineation of the map unit, the delivered hazard rating and reasons for the rating, and the specific activities that trigger erosion and delivery of sediment. The unit number and triggering mechanism can be placed on a Causal Mechanism Report (Form 4) at this time.

Surface Erosion From Roads Assessment

Unlike surface erosion from exposed hillslopes where revegetation usually occurs within a few years, road surfaces can continue to erode as long as the road is used. The road cutslope and fillslopes tend to revegetate, reducing erosion from those sources over time. However, road running surfaces continue to provide fine-grained sediments over the life of the road, especially when used by log trucks (Reid and Dunne1984). The focus of this part of the module is to identify roads producing a significant amount of sediment that affects public resources including water quality and fish habitat. This analysis develops an understanding of the overall effects of the road system on sediment yield by roughly quantifying the amount of sediment delivered to streams from roads in a sub-basin, and comparing that amount to the estimated background sediment rate.

The amount of sediment produced from the running surface of a forest road is determined by the amount and type of traffic (Reid and Dunne1984; Sullivan and Duncan 1980), construction materials and methods (Burroughs and King 1989), and the design of the drainage system (Reid 1981). Sufficient research has been conducted on the factors that influence road erosion on different parent materials that the sediment rate for a given road segment can be estimated according to these factors. Erosion rates from forest roads commonly having the range of traffic rates, surfacing materials, and drainage design can vary by as much as two orders of magnitude. Therefore, to appropriately estimate the potential for adverse effects from roads on public resources in a watershed, roads should be examined in some detail according to factors that influence sediment generation.

The approach for estimating sediment production is to examine road segments for characteristics of the road prism, drainage system design, and traffic, as they influence the delivery of sediment to the stream system, and calculate sediment yield based on them. Factors are applied for differing conditions of the road tread, cut and fill slopes, and traffic use that increase or decrease the estimated sediment yield of that segment as compared to the "Reference Road"(a compilation from the literature). The result is an estimate of sediment yield for each road segment for its expected traffic use rate. The estimate is further modified according to the average delivery of sediment to streams along that segment. The reference road is described as:

Reference Road

An insloped road with a ditch; native surface road tread and ditch; general use traffic (mostly pick-ups and sedans); cutslope gradient 1:1 (horizontal to vertical) and fillslope gradient 1.5:1; initial ground cover density of zero on cut and fill slopes; sustained grade of 5-7 percent; and an average cross-drain spacing of 500 feet. The proportions of the total long-term average road erosion rates attributed to the components of the standard road prism are:

Road Tread	40%
Cutslope and Ditch	40%
Fillslope	20%

(Swift, 1984; Burroughs and King, 1989; Sullivan and Duncan, 1980; Megahan, unpublished data)

Since it is usually not possible to visit every road segment in the WAU, the road system must be stratified, enabling sampling of portions of the system. Each road "type" can be characterized, and sediment yields determined and extrapolated to other roads of the same type. Road "types" consist of segments of similar use and construction standards. Once sediment yield has been estimated for each road type in the sub-basin, the relative effect of the entire road system on water quality and sedimentation can be evaluated.

Localized Road Problems

During the course of this assessment, the analyst may discover portions of the road system or local problem spots that contribute adverse levels of sediment to streams. These sites may or may not occur along a generally high sediment yield road segment type, or may or may not occur in a sub-basin with a generally high sediment load. In any case, these site situations are recorded on a site form so that these sites can be addressed according to standard rules where they are not addressed by prescriptions. The analyst cannot be expected to uncover every site problem during watershed analysis, but any site problems that are encountered can be addressed outside of watershed analysis through standard rules, no matter where they occur in the basin.

Table B-3, below, provides a general overview of the types of forest road situations, and their expected relative ratings for producing sediment that is delivered to streams. This table is not used in the analysis, but rather is provided to give the reader a general view of the of the types of road segments that produce High, Moderate, and Low ratings.

Table B-3: General Criteria for Sediment Production from Roads

Low	Moderate	High
Few roads	Moderate amount	Lots of roads
Ridgetop roads	Roads _|_ to streams	Roads paralleling streams
Cohesive soils	Moderately cohesive soils	Non-cohesive soils
CONSTRUCTION PRACTICES: Resistant surfacing (Good lift)	Surfacing less thick	Little or no surfacing or non-resistant materials
CUT SLOPES: Low-angle Surface protected cohesive materials	Higher angle Somewhat exposed Prone to ravel	High angle Exposed Highly susceptible to ravel
FILLSLOPES: Protected around streams especially	Partially exposed and of erodible soils	Exposed and of erodible soils and near streams
SURFACE DRAINAGE: Uniform, well-spaced culverts Insloped roads	Moderately spaced culverts Outsloped roads	Widely spaced culverts Berms on roads Rutting
TRAFFIC PATTERNS: Occasional traffic by log trucks	Occasional traffic, but occurring each year	Continual log-truck traffic
USE: Roads closed (put to bed)	Roads in non-use status	Roads open and used

Erosion Potential

The basis of this procedure is to examine representative segments of road to determine their condition relative to sediment-production factors. These characteristics are used to adjust the reference sediment yield up or down and produce a modified estimate of annual sediment yield from the road segment type.

Identifying Road Segments

Roads will be grouped into road segment types within the WAU, according to parent material, surfacing material, and traffic use. These groups represent the potential erosion road units. Road lengths with generally similar characteristics within that length are called road segments. A road segment is defined as a mile or more of road crossing similar topography and parent material, with similar construction and use. Criteria that distinguish road types are parent material, surfacing material, traffic use, and similar topographic positions.

Each forest landowner usually builds and maintains roads to a consistent standard based on anticipated use by log trucks, so there will often be obvious groups of road segments that share many characteristics of construction, maintenance, and use. Start-up materials include maps provided by the

Table B-4: Surfacing/Road Use Coding

	Abandoned	Inactive	Active Secondary	Active Mainline
Asphalt	AA	AI	AS	AM
Dust-oil	DA	DI	DS	DM
>6" Gravel	6A	6I	6S	6M
2 - <6" Gravel	2A	2I	2S	2M
Native	NA	NI	NS	NM

NOTE: For a description of road categories, see Table B-9.

landowners in the WAU displaying road surfacing and use. Use of this information, along with parent material and topography, will allow the analyst to break out road segments. Further grouping may occur where road prism geometry varies significantly from the Reference Road, or where sediment delivery percentages vary within the cluster.

During the Start-up phase, each landowner in the WAU is asked to provide a map of his/her roads, coded according to the type of surfacing and traffic use that occurs. The traffic use should reflect an average of use expected over the next 5 years. If the future road use is not known, the analyst may assume that the past 5-years use rate is a good representation.

The analyst produces a map of road use and surfacing coded according to Table B-4 below, for all roads in the WAU, labelling it *Map B-5*, "Road Traffic and Surfacing.

Analysis of Road Segment Groups

Road segment groups will be analyzed to produce estimates of rates of sediment delivery for each road segment type, and that rate will be applied to the segments of that type in each sub-basin, resulting in an estimate of sediment delivery from roads for each sub-basin. The amount of sediment delivered to the stream from each road segment type is estimated by apportioning the inherent erosion rate among the road prism components. Each component rate is modified by cover and contributing activities, and then the percentage of the road delivering sediment into the stream system is applied. The calculated number is the rate of sediment delivered to streams from road segment types. The rate multiplied by the amount of each segment type in each sub-basin will provide an amount of sediment from roads for each sub-basin.

Roads differ in the inherent erodibility, or *erosion potential,* due to the geology, or parent material on which they are constructed. In addition, factors that affect erodibility included in this analysis, are: road age, road surfacing material, and vegetative cover on cut and fill slopes. The key *contributing forest activity* is log truck traffic on roads.

The *delivery* of road erosion products to the stream system is key to understanding the influence of roads erosion on the stream system. Delivery is affected by the road drainage system design including road prism shape, proximity of the road to the stream system, and length of road draining directly into a stream channel at crossings. The characteristics of the road that affect delivery are part of the standard to which the road was built, and will be generally consistent across a groups of road segments. Where there are different delivery scenarios, the road segments can be regrouped to represent that.

Road Erosion Potential

For forest roads, the erosion potential is determined from three attributes:

1. The relative areas of the road in each prism component

2. The inherent erodibility of the parent material on which the road is constructed

3. The protection provided by cover materials (i.e. vegetation, woody material, surfacing rock, etc.) which reduce the exposure of soil to rainfall and traffic wear

Road Dimensions

The proportion of the road area for each road prism component must be determined. The dimensions of the Reference Road described previously are assumed. If field visits indicate that the dimensions of the prism components for a group of road segments do not resemble the Reference Road, the standard dimensions can be adjusted according to field estimates. Doing so will require the analyst to track the erosion rates by component, and adjust them accordingly.

Basic Erosion Rate

Various researchers have established inherent erodibility rates for roads built in different geologic materials, and these rates are displayed as the "Basic Erosion Rates" for "Old" and "New" roads in Table B-5. The rates represent erosion from bare road prism surfaces of the Reference Road built on each parent material type. The different rates associated with "old" and "new" roads reflect the tendency for recently exposed soils to "armor", as the finer soil particles are washed from the surface.

The analyst determines which group of parent materials is most similar to the parent material of each road segment, or road segment type. The analyst may wish to consult with the Mass Wasting analyst for assistance in choosing the appropriate basic erosion rate.

The Basic Erosion Rate is apportioned to the cutslope/ditch, fIllslope, and tread, accor ding to the percentages given for the Reference Road.

For example, sediment production from one acre of a 2-year-ld road built on Coarse-grained granite material would be, for the various prism components:

Tread	40% of 110 = 44
Cutslope/Ditch	40% of 110 = 44
Fillslope	20% of 110 = 22

Table B-5: Basic Erosion Rates

Numbers represent erosion rates in Tons/acre of road prism/year.

		Road Age	
General Category	Parent Material	New 0-2 Years	Old > 2 Years
High	Mica schist Volcanic ash Highly weathered sedimentary	110	60
High/Moderate	Quartzite Course-grained granite	110	30
Moderate	Fine-grained granite Moderately weathered rock Sedimentary rocks	60	30
Low	Competent granite Basalt Metamorphic rocks Relatively unweathered rocks	20	10

(Kochendorfer, J. N. and J. D. Helvey 1984; Hayden et al. 1991; Megahan and Kidd 1972; Reid and Dunne 1984; Sullivan and Duncan, US Forest Service unpublished data)

Cover Factors for Cut and Fill Slopes

(Erosion Potential)

Erosion rate from cutslope and fillslope parts of the road prism are altered according to the amount of cover on these surfaces. “Cover” refers to all surfaces other than soil, and could typically include vegetation, rock, slash, or erosion control materials. The Reference Road has unvegetated cut and fillslopes, so cover protecting these slopes will reduce the basic erosion rate. Specific reduction factors for erosion control materials can be found in Burroughs and King (1989) or other sources. Table B-6 provides factors for adjusting erosion rates for cover density.

Table B-6: Correction Factors for Cut and Fill Slopes

Ground Cover Density	Factor
>80%	0.18
50%	0.37
30%	0.53
20%	0.63
10%	77%
0%	1.00

(Megahan 1991; Burroughs and King 1989; Megahan unpublished data)

For example, for the cutslope and fillslope in the previous example, with a basic erosion rate of 44 Tons/year, and a vegetative cover of 50% on the cutslope and a basic erosion rate of 22 Tons /year and 80% vegetative cover on the fill slope, the adjusted basic erosion rates will be:

Cutslope: 44 X 0.37 = 16.28 Tons/year
Fillslope: 22 X 0.18 = 3.96 Tons/year

Surfacing Factor for Road Tread

(Erosion Potential)
Road surfacing material and construction determine the erodibility of the surface tread with log truck and other types of traffic. Road surfacing material and history can be determined by information from landowners and field observations. Road prism factors are provided in Table B-7, Factors for Road Tread Surfacing, to be used to adjust the erosion rate for surfacing. The Refer ence Road is native surface, so any surfacing material will reduce the erosion from the road surface.

Table B-7: Factors for Road Tread Surfacing

Surfacing Material	Factor
Paved	0.03
Dust-oil	0.15
Gravel, > 6" deep	0.2
Gravel, 2" - 6" deep	0.5
Native soil/rock	1.00

For example, In the previous example, with the road tread basic erosion rate of 44 Tons/year, and a thick gravel surface, the adjusted erosion rate would be:

22 X .20 = 4.4 Tons/year

We now have adjusted rates for all the prism components, based on the amount of cover:
Tread: 4.4
Cutslope/Ditch 16.28
Fillslope 3.96

This erosion rate can be thought of as the “erosion potential” for the road. Traffic will be analyzed next as the “contributing activity”.

Traffic Characteristics - “Contributing Activities”

Perhaps the single greatest factor affecting generation of sediment from road surfaces is the amount of traffic (Reid and Dunne 1984; Sullivan and Duncan unpublished). Although forest road surfaces are generally constructed of resistant materials such as gravels, traffic can grind the road surface into smaller particles that can be transported by rainfall runoff into ditches and potentially into streams. Traffic rate determines the quantity of sediment available for transport, while the rainfall determines the transport capacity.

Table B-8 correlates traffic rate with mean annual rainfall to provide a road tread erosion factor. One source for determining the mean annual rainfall for the WAU is the precipitation frequency atlas published by the National Oceanic and Atmospheric Administration (NOAA) (Miller et al. 1973). Consultation with the Hydrology analysis team can also help in providing this information.

Table 8: Traffic/Precipitation

The traffic and road categories are described in more detail in Table B-8, Traffic Definitions.

	Annual Precipitation		
Traffic Use/Road Category	**<1200 mm**	**1200 mm - 3000 mm**	**>3000 mm**
Heavy Traffic/Active Mainline	20	50	120
Moderate Traffic/Active Secondary	2	4	10
Light Traffic/Not Active	1	1	1
No Traffic/Abandoned	0.02	0.05	0.1

(Reid and Dunne 1984; Sullivan and Duncan unpublished)

Table B-9: Traffic/Road Category Definitions

Traffic Category	Road Category	Estimate of Long-Term Average Use
Heavy	Active Mainline	Road is actively used and maintained for log haul traffic. Receives log haul traffic more than 50% of the time during the year.
Moderate	Active Secondary	Road receives log haul traffic up to 50% of the time. These are typically well-maintained major spur roads that provide access to larger areas.
Light	Non Active	Traffic limited to pick-up traffic the majority of the time, with occasional log truck traffic. This will usually be a spur road accessing areas that rarely have log haul.
None	Non-used	Roads that are rarely used and are typically blocked to 4-wheel drive highway vehicles. This category includes both roads where drainage structures are left in a condition to minimize erosion in the absence of maintenance and those without erosion control, or orphaned roads.

For example, the tread erosion rate in the previous example was calculated at 4.4 Tons/year. If that road is an active secondary road with moderate traffic in a basin with 1500 mm precipitation per year, the erosion rate is:
4.4 X 4 = 17.6 Tons/year

A *Level 2* assessment may refine the traffic factor for particular roads based on more detailed traffic information. More detailed information may include seasonal closures, hauling restrictions, and variable traffic rates. Document the reasons for any change in road use factors.

The factors shown in Table B-8 are adjusted for the amount of time the road receives the use indicated on a long-term average basis, but they can also be applied on an annual basis.

For example, the previous example road, in a basin with 1500 mm annual precipitation, but has heavy truck traffic for 3 months (25%), moderate traffic for 6 month (50%), and light traffic for 3 months (25%), would have a factor of 14.75:
(.25 X 50) + (.50 X 4) + (.25 X 1) = 14.75

This factor is then multiplied by the basic erosion rate for the road segment:
14.75 X 4.4 = 64.9

The above level of detail is usually associated with a Level 2 analysis.

Sediment delivery from roads to streams

Sediment from road surfaces is routed from the road prism through flowing water, which occurs in roadside ditches, gullies, culverts, or in some cases as overland flow. Although all roads generate erosion, only a portion of the road system drains into the stream system. Road runoff from parts of the system drains onto permeable soils where the sediment is deposited as the runoff infiltrates. The percentage of road length with stream entry varies between individual roads and watersheds, due to stream and road densities, road drainage design, topography and other factors (Sullivan and Duncan unpublished). It is important to determine what proportion of the sediment from a road system is delivered to streams in order to evaluate the contribution of road surface erosion to downstream resources.

Delivery from Prism Components

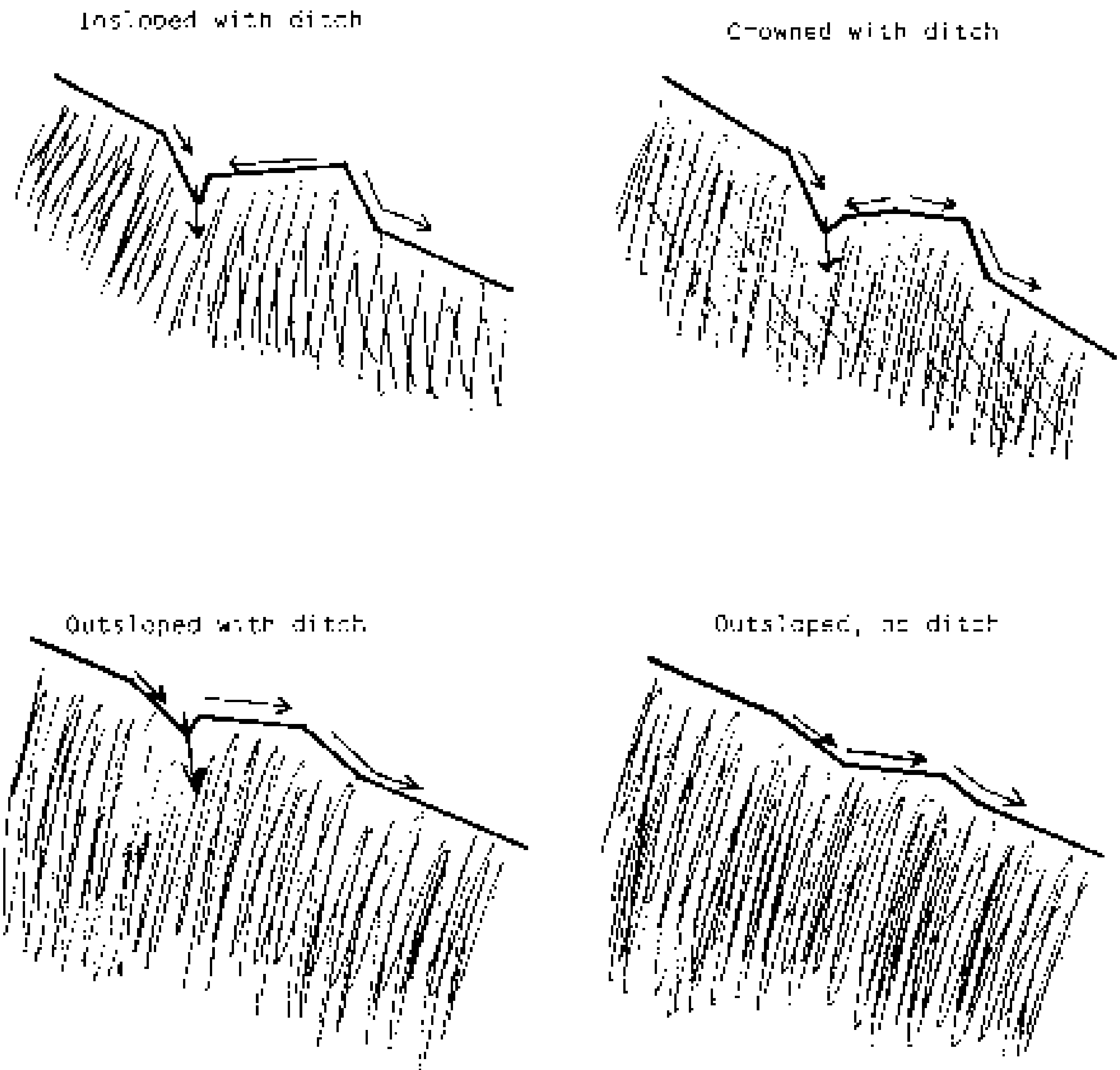
The drainage design of a road strongly influences the amount of sediment delivered to streams. Two aspects of the drainage are important: (1) the ditching and drainage system as it connects to stream channels, and (2) the cross-sectional design of a road dictates the flow of water from the road prism either toward or away from the ditch. Both aspects are used to determine the road sediment delivery.

Where runoff from fillslopes is dispersed onto permeable soils below, infiltration may prevent sediment delivery to a stream located downslope. On the other hand, if fillslope runoff continues downslope as overland flow or reaches an active gully, sediment may be routed to a stream. The orientation of the tread (i.e., insloped, crowned, or outsloped) determines whether runoff from the tread drains into the ditch or over the fillslope. Crowns and outslope must be maintained, or they may function more like an insloped road. Field observations can determine the correct call for the road segment type.

Delivery can be adjusted by determining the portion of the road surface draining to the ditch according to the prism configuration. Road prisms can be divided into four cross-sectional designs, as illustrated in Figure B-3, Road Prism Cross-sectional Design.

Although the flow paths of road surface drainage could be mapped at a very fine scale, the analyst will use a generalized characterization of the prism configuration to determine pathways for a road segment or group of similar segments.

Figure B-3: Road Prism Cross-Sectional Design



Drainage To Streams by Ditches

For an individual road segment, the length would be divided into the sections that drain into each drainage site, i.e., the place where water is directed away from the road prism, often a culvert, ditch-out or bridge. At each drainage site, the potential for sediment delivery to the stream is determined. The delivery percentage for each drainage section is based on three rules:

1. If the road drains directly to a stream channel* via a ditch or gully: Assume 100% delivery from the parts of the road that drain directly to the stream. The fill slope does not drain down the road ditch, and delivery from the fill slope should be considered separately.

2. If the road drains onto a hillslope within 200 feet of a stream: Assume 10% delivery from that section.

3. If the road drains onto a hillslope more than 200 feet from a stream: Assume 0% delivery from that section.

* A “channel” is defined as any drainage depression containing a defined bed and banks, extending continuously below the drainage site. The flow regime can be ephemeral, intermittent, or perennial.

Rule #2 above was developed from Idaho research (Ketcheson and Megahan unpublished) that showed that sediment flow from most cross drains extends less than 200 feet, and that 90% of the sediment volume was deposited within the first 40% of the maximum length. If the analyst observes evidence that this rule of thumb is not appropriate for a group of segments, then the analysis should reflect the more accurate rates of delivery, with explanation for rates used.

For Example:

If field visits to road segment type from the previous example showed that about 30% of the length of the segments drained directly into a stream channel, about 30% drained to within 200 feet of the stream, and the remainder did not drain to a stream, the following calculation would give the delivery percent:

Adjusted Tread Rate (Mod Traff):	17.6	Tons/year
Adjusted Cutslope/Ditch Rate:	16.28	Tons/year
Adjusted Fillslope Rate:	3.96	Tons/year
	37.84	Tons/year/Acre of Road prism

((.30 x 1.00) + (.30 x .10) + (.40 x 0)) x 37.84 = 12.49 T/yr/Acre of road prism

This 12.49 is the erosion rate for these segment types. The units are still *Tons/acre of road prism/year*, the same as the Basic Erosion Rate. All adjustments were by dimensionless factors.

The result is in U.S. Tons. Convert to Metric Tonnes for comparison with background sediment calculations by multiplying the road sediment figures by 1.1. The delivered sediment rate calculated at this point is applied to all segments in the group. The length and average width of each segment type is used to calculate the acres of road prism of each segment type in each sub-basin. Delivered sediment is calculated for each sub-basin.

For example, assume the following segment types and lengths for these sub-basins:

Sub-basin A	Length	Avg. Width	Rate	
1. Active mainline	1 mile	30'	35	Tons/acre of road prism/year
2. Secondary	3 miles	25'	12	Tons/acre of road prism/year
3. Not active	13 miles	18	4	Tons/acre of road prism/year

Segment Type 1
(5,280' x 30')/43,560 sq ft/acre = 3.6 acres of road
3.64 acres x 35 Tons/acre road prism/year = 127.4 T/yr
Segment Type 2: ((3 x 5,280 x 25)/43,560) x 12 = 109.09
Segment Type 3: ((13 x 5,280 x 18)/43,560) x 4 = 113.45
Sub-basin Road Sediment Total: 349.94 T/yr

The analyst is encouraged to develop an electronic spreadsheet to calculate estimated road-generated sediment rates and amounts. Whether electronic or hand-made, a calculation form, labeled *Form B-2*, “Roads Calculation Sheet”, will be included in the final report, as an appendix, and will include at a *minimum*, the following information:

- WAU
- sub-basin
- road segment type
- length of the road segment type in sub-basin
- basic erosion rate
- % area of each prism component if other than Ref Road
- cover factors for cut and fill slopes
- surface factor for road tread
- traffic factor
- rate of erosion for each prism component
- delivery percentage
- sediment delivery rate and amount for segment type
- total amount of sediment from roads for sub-basin

Exact format of the calculation sheet is left to the analyst.

Field Sampling for Roads

The analyst develops a field sampling scheme to visit sufficient samples of each type of road segment to be able to estimate sediment with reasonable confidence. It is expected that these will be more sampling of the segment groups with the most miles, and those likely to be high contributors of sediment.

These field visits are used to verify traffic and surfacing information provided by landowners, to verify segment types and grouping, to check average road width and percentages of prism components, to collect information on cover percents on cut and fill slopes, to locate localized problem areas, and to check delivery percents.

The analyst can use any field data collection methodology and form that they choose. However, field data is expected to be included in the module products. Appropriate materials should be labeled *Form B-3* , "Road Field Form", that will include at a *minimum*:

WAU
Sub-basin
road identifier
road type (landowner information)
agreement/reasons for disagreement with road type
% area of each prism component if other than Ref Road
cover percentages for cut
cover percentages for fill slopes
delivery percentages

The field forms will be included with the final report as an appendix.

A final roads map, labelled *Map B-6*, "Road Segment Delivery", will be developed showing various segment types and rates of delivery as they occur in each sub-basin. This map will be useful in determining "triggering mechanisms" for basins rated Moderate or High (see "Determining Sensitivity" in the "Potential Effects of Land Use Activities on Sediment Yield" section).

Summary Table

A summary table, labelled *Form B-4,* "Surface Erosion Summary", of information from calculations of road sediment should be prepared that will include, at a *minimum*:

WAU
Sub-basin
Each Segment Type
Total sediment rate
Contributions from
  Cut slope

Fill slope
Tread and traffic
Delivery percentage
Comparative rankings of segment types for sediment delivery

The amounts and comparative rankings will be useful in describing the triggering mechanisms for the Causal Mechanism Reports.

Effect on Public Resources

All managed watersheds are likely to have some increase in sediment yield over pristine conditions. The purpose of this assessment is to locate areas in the watershed likely to experience significant changes in sediment that result in chronic changes in turbidity or deposition of fines in stream beds affecting aquatic life. Sediment yield in a watershed is highly variable from year to year reflecting climate pattern (Beschta 1978). Sometimes varying as much as an order of magnitude annually, differences in sediment yield can be difficult to detect statistically. Some evidence has shown that sediment yields increased by 50% or more of the long-term average are detectable with water sampling procedures (Sullivan pers com). To develop a relative indication of the increase in fine sediment yield from roads and hillslope erosion, an estimate of sediment production must be developed to provide a means for comparison.

The analyst should determine the sub-divisions of the WAU most relevant comparing background and management-related sediment input, preferably following consultation with fish and channel analysts. Useful sub-divisions for comparison could be fish-bearing sub-watersheds, or the entire upslope area contributing to a stream location sensitive to fine sediment, due to fish habitat or water quality concerns.

Some helpful conversion factors:

1 U.S. ton (2,000 lb) = 0.907 metric tonne (also megagram, Mg)

1 metric tonne or megagram (Mg) = 1.10 U.S. ton

1 metric tonne or megagram (Mg) = 1,000 kilograms

1 gram/cubic centimeter (g/cc) = 1 tonne/cubic meter

Bulk density of soil
Bulk density may be given in kg/cubic meter and ranges from around 1200 kg/cubic meters to 1700 kg/cubic meters (Soil Conservation Service 1986).

Bulk density may also be given in tonnes/cubic meter. Bulk densities given in grams/cubic centimeter also range from 1.2 to 1.7 g/cc.

Background Sediment Yield

Rates of fine sediment production can be estimated using several approaches. One approach would be to determine sediment input rates from each of the significant input processes operating in the watershed, creating a partial sediment budget. This "Sediment Budget" approach could utilize field observations, aerial photos and maps and be relatively elaborate or simple, depending on the importance of sediment input issues within the basin. The Soil Creep Model, explained below, is a relatively simple form of the Sediment Budget approach.

A second approach would be to utilize sediment yield data from a river or stream comparable to the study watershed, which would reflect the net output of sediment from all upstream sources. Under this "Sediment Yield Data" approach, data from comparable watersheds would be used to estimate background output rates for the study watershed. The analyst can determine which approaches are most appropriate, depending on local watershed conditions, available information and the confidence level required for the issues specific to the study watershed. Table B-9 provides some general guidance for the selecting between two standard approaches for estimating background sediment.

Table B-9. Sub-watershed and responses reach conditions that support the use of the Soil Creep Model vs. Sediment Yield Data methods for estimating background sediment production.

	Prevalent Conditions	
Sub-watershed or response reach attribute	Preferred Method Soil Creep Model	 Sediment Yield Data
Location of response reach	Headwaters (order 1-3)	Lower basin (order 3+)
Prevalent valley morphology	Channels confined by valley walls	Alluvial reaches located upstream
Magnitude of inputs from mass wasting and/or alluvial bank cutting	Low	High[1]
Quality of information on soil depths & drainage density	Good	Poor
Availability of sediment yield data from comparable watersheds[2]	Poor	Good

[1]In some cases, this can be resolved by supplementing soil creep inputs with estimated input rates for other processes.

[2]Watersheds should be somewhat comparable in terms of geology, topography, land use, etc.

Sediment Budget Approach

Because sediment derived from surface erosion processes activated by land use practices generally consists of finer-grained particles, the estimate of background input or output rates should be confined to the proportion of fine particle sizes. In mountainous watersheds, soil creep, mass wasting, and alluvial bank cutting are often the major input processes.

In many basins, the dominant natural source of fine-grained weathered sediments is soil creep. The classical definition of soil creep is the slow downslope movement of the soil mantle under the influence of gravity, although other soil displacing processes, such as tree wind-throw and animal burrowing are generally reflected in estimated rates of soil creep as well. Back-calculations from sediment yields suggest that soil creep provides sediment at a rate equivalent to between 1 and 2 mm/year along the entire channel length. For basins where creep dominates, the soil creep model described below may be adequate.

In basins where mass wasting or alluvial bank cutting processes are major sources of fine sediment, an alternate approach may be necessary. Where inputs rates from non-creep processes can be identified, evaluation using field or aerial photo investigation can be used to supplement the sediment input budget. Alternatively, the Sediment Yield approach may be useful for some situations (Table B-9)

The factors used to calculate annual soil creep erosion rates are length of the stream channel in the basin, average soil depth, and the creep rate as a length per year. If this assumption is grossly in error in a given watershed, then results of this portion of the assessment may have low confidence.

Stream Channel Length (L)

For this assessment the amount of sediment introduced to the stream system is estimated as the total of hillslope volume delivered to Type 5 and larger streams. Estimate the length of Type 1-5 streams in the sub-basin in meters which can generally be easily determined using a GIS or topographic maps. However, different maps provide varying levels of accuracy in identifying small streams, which my constitute a large proportion of the total stream length. Some spot-checking of the upslope extent of incised channels is justified in many watersheds to adjust for systematic mapping errors. The total stream length is multiplied by two to account for both sides of the stream.

Soil Depth (D)

Soil depth can be generalized over the sub-basin using soil maps and field reconnaissance for verification. Rough approximations are sufficient for this crude sediment budgeting approach. Road cut banks and stream banks offer point for observation of soil depth sufficient for this assessment. If soil depth is significantly deeper than 2 meters, estimate the depth as accurately as possible. Soil surveys usually provide sufficient information to estimate average soil depth over a sub-basin.

Soil Creep Rate (C)

Relatively little research has been conducted on rates of soil creep, especially in typical forested mountain watersheds. Creep may be influenced by soil and rock material, hillslope hydrology, and slope angle. For simplicity, we use only slope gradient as the primary estimator of creep rate: If average slope is less than 30%, then use a creep rate of 0.001 meters/year. If average slope is 30% or greater, use 0.002 meters/year. If the analyst has a better estimate of creep rate, they are encouraged to use it.

Calculation of Background Rate:
Annual Erosion Volume (m^3/yr) = L (m) *2*D (m) *C(m/yr)

Sediment yield in metric tonnes per year is approximately equal to 1.5 times erosion volume, assuming bulk density of the soil to be about 1.5. This assumption may be modified if better information is available.

Sediment yield = (1.5 X Erosion Volume) You should correct total volume to delete the coarse sediment particles. The proportion of coarse particles can often be determined using soil survey information.

The Background Rate has been calculated in metric Tonnes. The road sediment was calculated in US Tons, so conversion to a common format is needed for comparison. Field managers are generally more familiar with US Tons and acres, as opposed to metric Tonnes and hectares. Provide information in both formats to facilitate comparison with other scientific literature in metric measures, and to meet the needs of field managers in US measures.

Sediment Yield Data Approach

Where available, sediment yield data can provide an empirically-based means of estimating of background sediment production. Much of the published sediment yield data is compiled in the Erosion and Sedimentation Catalog of the Pacific Northwest (Larsen and Sidle 1980), but other data may be available from the USGS or other agencies. However, data from sampling that did not cover an extended time period and range of flow levels is unlikely to provide a valid long-term average. Sediment yields that refer specifically to suspended sediment particles is the most relevant for comparison to inputs generated from surface erosion. In many cases, fine sediment yield data can be estimated from data for total sediment yield by converting using a reasonable bedload proportion.

Interpretation of measured sediment yield is complicated by the fact that rates incorporate sediment input from both land-use and natural erosion processes in the entire basin above, which may differ from the sub-watershed being analyzed. The analyst should recognize that yield data from many basins do not represent pristine conditions for comparison. For these reasons, it is important to consider the location where sediment samples were collected to determine the similarity to the sub-watershed you wish to extrapolate data toward.Geology, topography,the extent of forestry and other land uses all may be important factors that affect the suitability for extrapolation.

For example, sediment yield could be estimated from a 5,000-acre sub-watershed in the Chehalis River Basin using published yield data (Larsen and Sidle 1980):

Average annual suspended sediment yield - Chehalis River:
136 tons/mi^2 X 0.35 (conversion factor) = 47.6 tonnes/km^2

Sub-watershed area:
5,000 acres 247 acres/km^2 (conversion factor) = 20.2 km^2

Annual Sub-watershed sediment yield:
47.6 tonnes/km^2 x 20.2 km^2 = 962 tonnes.

Potential Effects of Land Use Activities on Sediment Yield

Hillslope Erosion

Based on the findings of the Hillslope Erosion Analysis, the analyst should estimate the rate of sediment input from hillslope surface erosion processes. If evidence of surface erosion was either absent or thought to be minimal (i.e. 2 or more orders of magnitude less than input from roads), then inputs can be ignored. If the analyst did discover significant areas actively contributing surface erosion, they should estimate an erosion rate due to surface erosion and multiply by the area of the watershed affected.

Roads

Sediment delivery rates for each road segment have been determined in previous steps of the assessment. The road erosion rate is multiplied by the length of the road segment type in the sub-basin to determine the road sediment yield.

Determining Sensitivity

The total amount of sediment is determined by summing the land-use related sources. The relative importance of land use related sediment is determined by comparison with the baseline sediment yield. If sediment is increased by 50%-100%, the effect of the sediment may be small, but chronically detectable. If the increase in total yield is more than 100%, the change in annual sediment yield is likely to be large enough to exceed water quality standards. In this case, the hazard rating for surface erosion is rated as Moderate (or High).

The analyst should interpret results with caution however. This sediment budget technique is crude in that neither natural or land use erosion processes are documented very thoroughly with field observations. The estimate of baseline sediment yield is likely to be in the neighborhood of reality, even at this gross scale of generalization. For example, if soil depth estimates of 0.5 meters to 2 meters are used, the baseline erosion estimate will usually calculate to be 6 to 50 tons/km^2 .These are close to measured values from Pacific Northwest mountain streams (between 6 to 100 tons/km^2). (Larsen and Sidle 1980). However, calculated road erosion rates can vary by an order of magnitude depending on the assigned traffic use rate, construction conditions or delivery features. Once the crude sediment budget is constructed, the analyst should first weigh whether the estimates in either land use or baseline erosion rates make sense before interpreting the severity of sensitivity to surface erosion. The conclusion may also be cross-checked with observations of impacts of fine sediment to stream channels were observed by the fish or channel analysts (i.e., V* values or particle size samples) for confirmation during synthesis.

If moderate or high sediment yields are determined for the roads, the analyst should determine which roads are contributing significantly and what factors are driving the rates up. These can be identified as road erosion units, and the factors leading to high sediment yield are identified as the triggering mechanism.

Surface Erosion Assessment Report

The Surface Erosion Assessment Report organizes and presents results of the surface erosion assessment. The report is a compilation of key work products, maps and narrative summarizing interpretations. Narrative may be on the order of several pages long and provide a concise discussion summarizing results of each section of the analysis module. While the Surface Erosion Assessment Report should be concise, it should be complete enough so that, together with the other module products, it provides the input necessary for the synthesis and prescription phases of Watershed Analysis where the information developed in the analysis modules is incorporated into land use decision making.

Realistically, there will not always be the type of data or information available that the analyst would desire for high confidence in the analyses and interpretations. Assessment of the confidence level possible based on available information thus may be important for decision-making based on these analyses. The degree of confidence that can be assigned to the products of this analysis depends upon a number of factors. Considering the amount, type, and quality of available information, analysts should determine their relative confidence in the interpretation based on each work product. Other factors to consider in this evaluation may include, but are not limited to, extent of field work, experience of the analyst, complexity of the geology and terrain, aerial photographs and map quality, and multiple lines of evidence for inferred changes.

Surface Erosion Assessment Report

I. Title page with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. Table of contents

III. Maps
- Hydrologic Analysis Unit (HAU) map (map B-1)
- Preliminary soil erosion potential map (map B-2)
- Past 5 years activities map (map B-3)
- Final soil erosion potential map (map B-4) with map unit descriptions
- Road traffic and surfacing (map B-5)
- Road segment delivery (map B-6)

IV. Summary Data
- Hillslope field/photo information (form B-1)
- Roads calculations worksheet (form B-2)
- Roads field forms (form B-3)
- Surface erosion summary (form B-4)

V. Summary Text
- Description of network-wide influences on surface erosion
- Study methods, including parameters used in background calculations
- Hillslope erosion conditions and activity situations
- Methods and rationale for developing Map B-4
- Narrative describing road conditions in the landscape
- Narrative providing interpretation of results in assessing surface erosion effects on public resources
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Statement of the author's confidence level in the analysis and results
- Does module report address all critical questions?

VI. Other Information (optional)
- Monitoring strategies and design and implementation suggestion
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments

If Level 2 analyses have been performed, the report should include a description of methods and results. All module work products should be archived for use during the Synthesis of this assessment and in future years.

Checklist for Project Management

Below is the Surface Erosion Module checklist, provided to guide the surface erosion analyst through the administrative steps of resource assessment. It will be especially useful if there is a team conducting the assessment. Note: The hillslope and roads preliminary work can proceed concurrently, review of preliminary products can be done concurrently, and the field work can be done concurrently. The order of listing below is not meant to imply the order of occurrence. Steps are included for review among members of the surface erosion team to aid in keeping the team updated and together as steps are completed.

Analysis materials in place

Start-up meeting for module team
- brief team on process and intent
- develop schedule

Develop Map B-1, subdividing the basin
- work with Hydrology team on this

Hillslopes Preliminary Work

Develop Map B-2, Preliminary Surface Erosion Potential Map

Develop Map B-3, Past 5 Years Activities for the basin

Examine aerial photos, begin filling in Form B-1

Develop field sampling scheme and for hillslope sites

Review preliminary hillslope products and sampling scheme with members of the surface erosion team

Roads Preliminary Work

Develop Map B-5, Road Traffic and Surfacing for the basin

Begin Roads Calculation Spreadsheets, Forms B-2

Develop Roads Field Form, Form B-3

Develop field sampling scheme for roads

Review preliminary roads information and sampling scheme with member of the surface erosion team

Field Work

Carry out hillslopes and roads field sampling scheme, filling in Form B-1 for hillslope sites and Form B-2 for roads.

Review results of field work, plan/design final products with the surface erosion team

Prepare Draft Final Products - to be used in Synthesis

Prepare Draft Final Surface Erosion Potential Map, Map B-4, with narrative description of surface erosion map units

Prepare narrative report explaining how information was used to produce final map, and describing systematic hillslope erosion problems and activity situations

Complete roads spreadsheets

Prepare narrative report interpreting roads information

Review final products with the surface erosion team

After synthesis:

Finalize maps

Prepare Final Surface Erosion Assessment Report, including field forms and spreadsheets

Acknowledgments

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